Electromagnetic Design of Diffractive, Micro Cavity, and Photonic Band Gap Devices

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Outline

- Electromagnetic Analysis and Design of Micro-Photonic Devices

- Applications for WDM

    – Embedded spectrometer

    – Photonic band gap filtering

- Diffractive Optic Design for On-Axis Spectroscopy

    – *f/#* dependence chromatic dispersion

    – Wavelet based multiresolution optimization

    – Fabrication of meso-scopic grayscale DOEs

- Photonic Band Gap Filters

    – Band Gap Design for finite length PBGs

    – Cavity arrays for WDM

   – Active semiconductor modeling

Why Electromagnetic Models Are Necessary

- As the scale of photonic devices approach the wavelength of operation boundary coupling effects significantly influence the EM fields on the boundary.

- This effect must be fully accounted for in the solution to the boundary value problem.

- This precludes the use of scalar and various other approximate methods.

coupling region

Breakdown in scalar approximation from right to left

off-axis lens
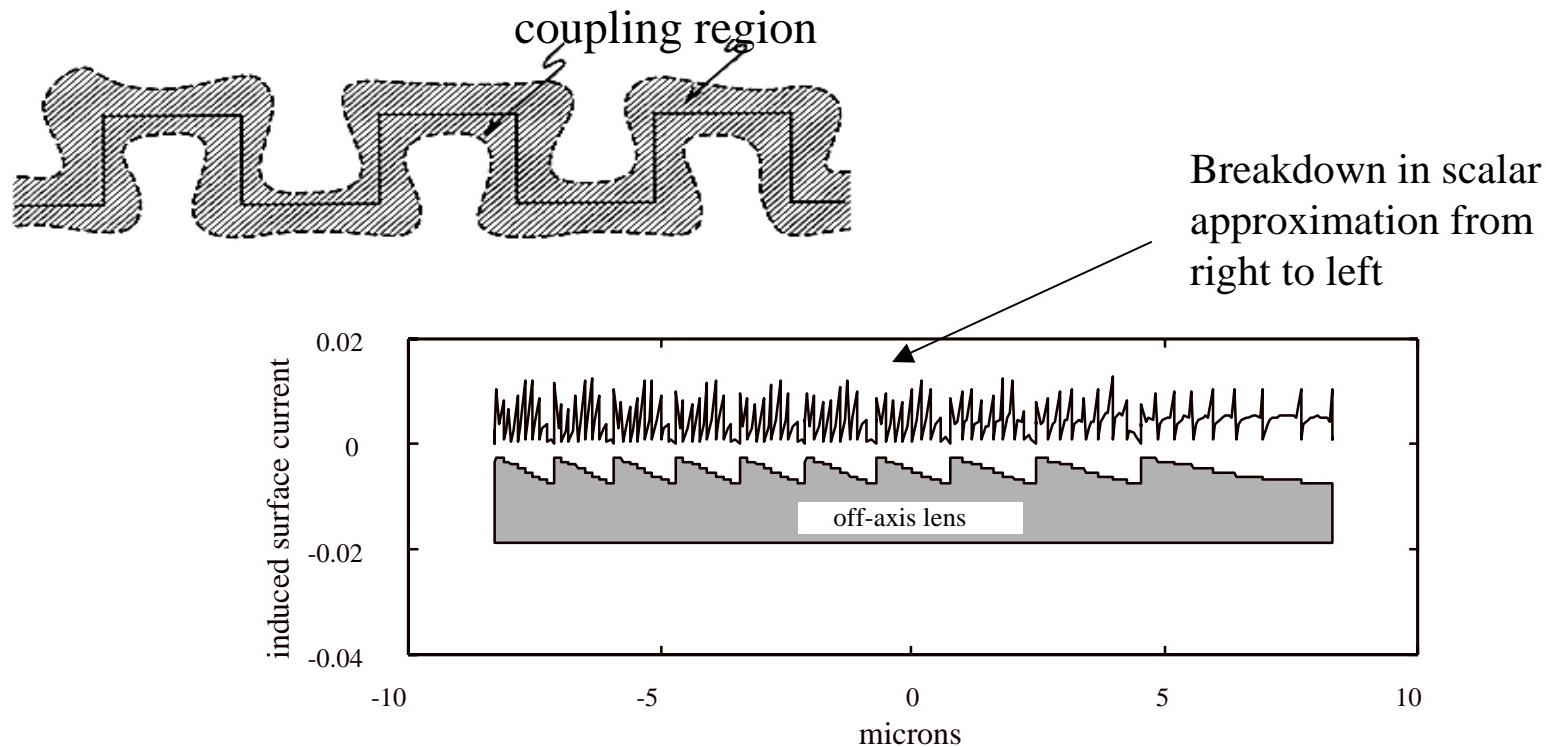
3D Diffractive Lens Analysis Results
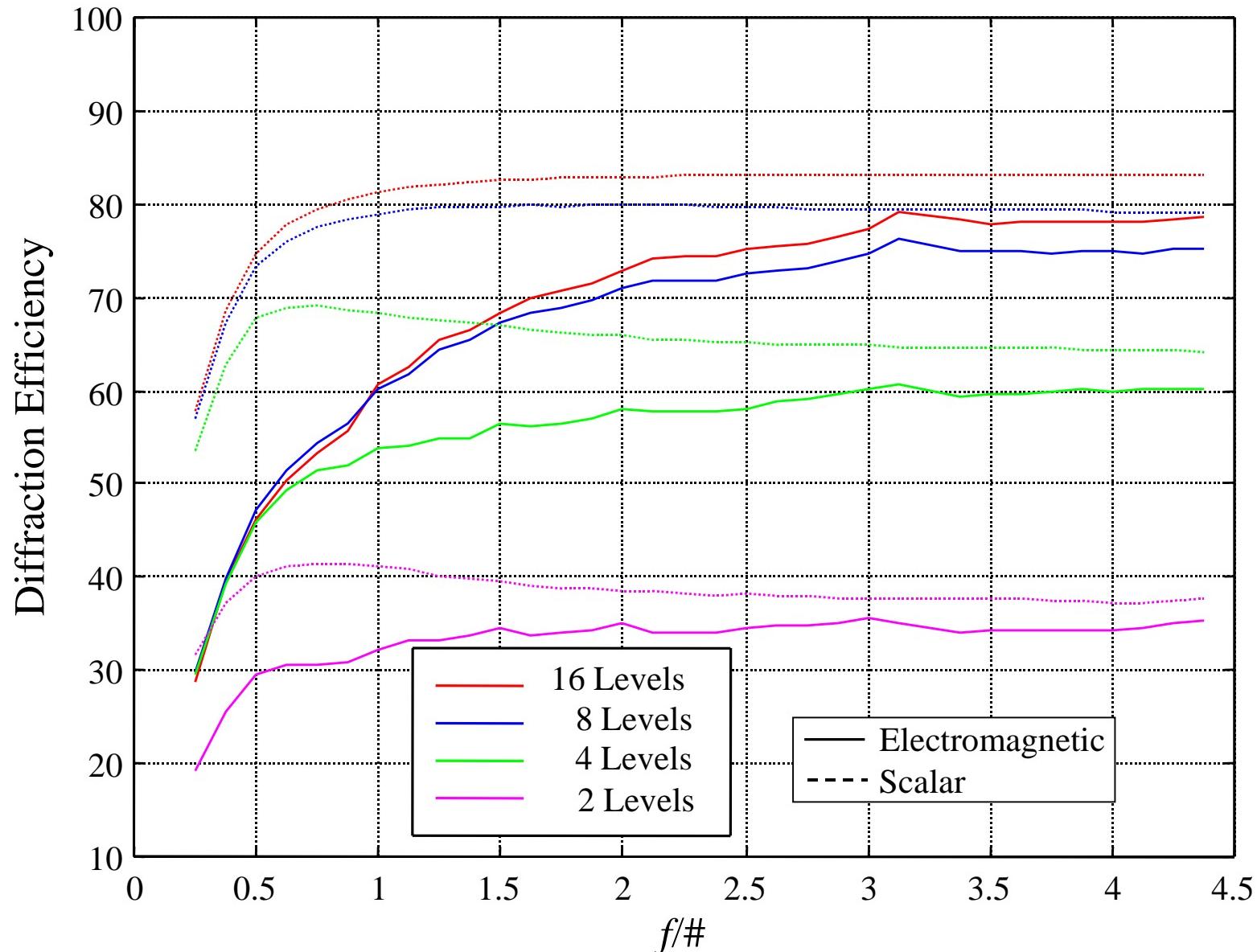
Computational Lattices In Three-Dimensions

BOR FDTD Unit Cell
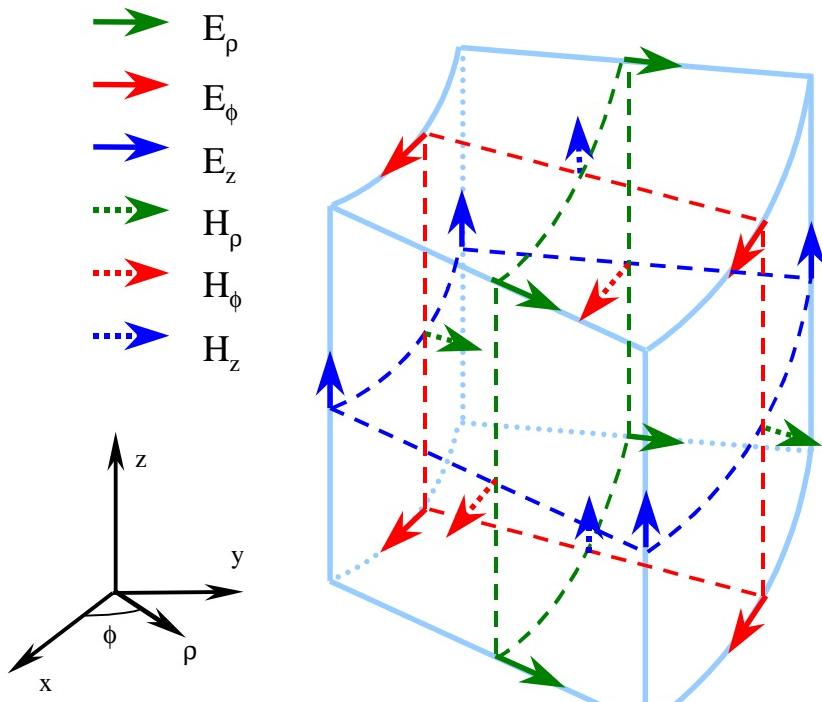
Full 3D FDTD
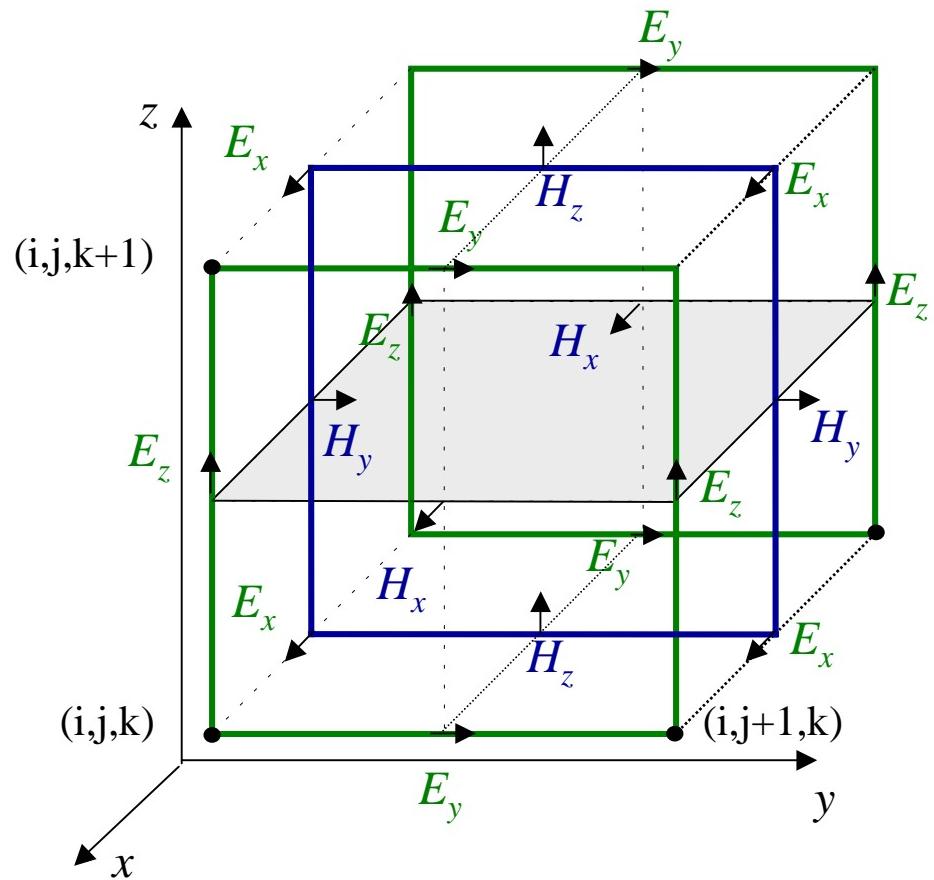
Application I: Embedded Spectrometer

Diffractive lenslet array

z-axis scan for filtering

Different wavelengths focus to different axial locations

ROIC

Detector array

Light gathering microlenses
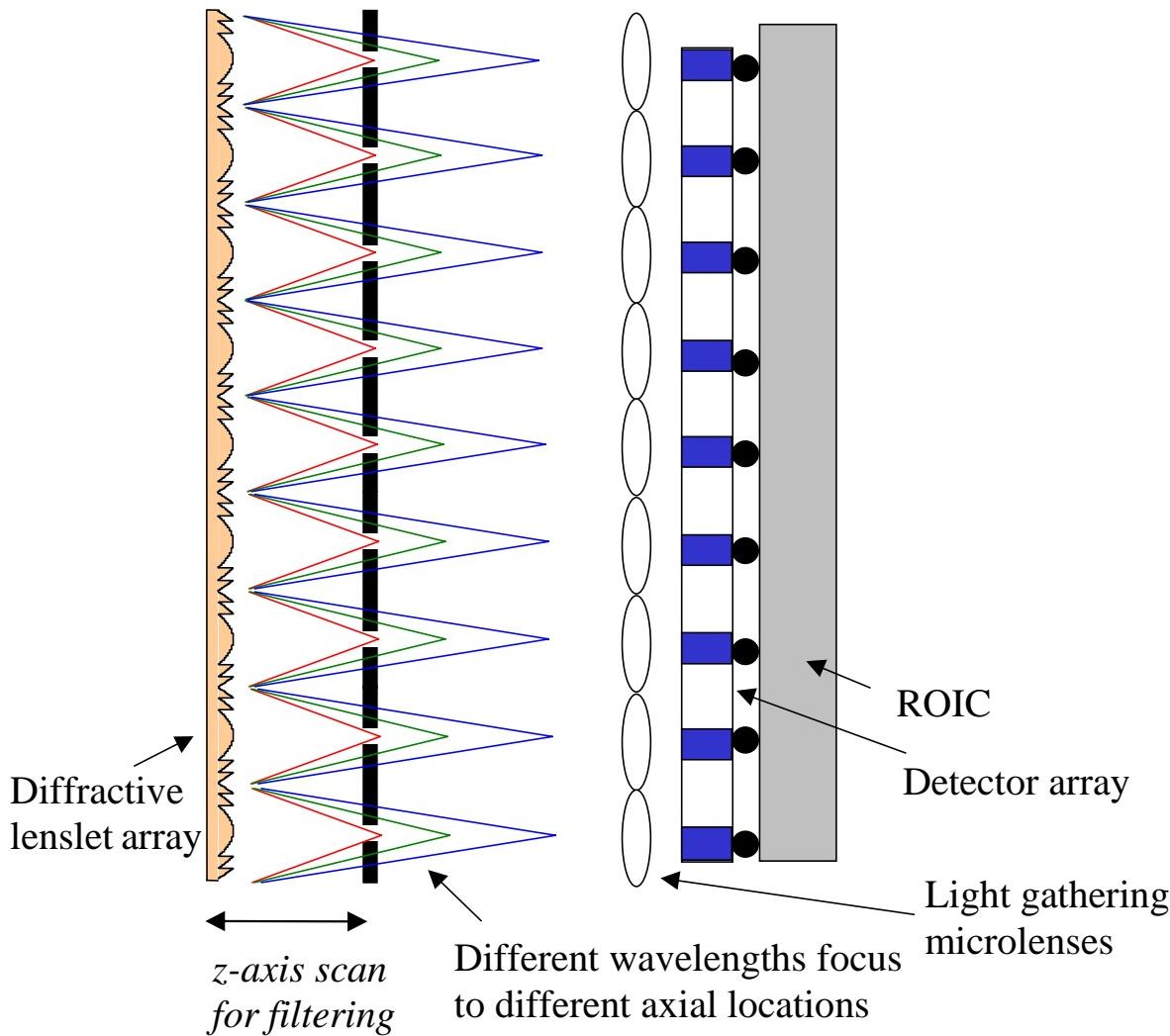
Application I: Scanner Development

Collaboration with Chemnitz University of Technology, Germany
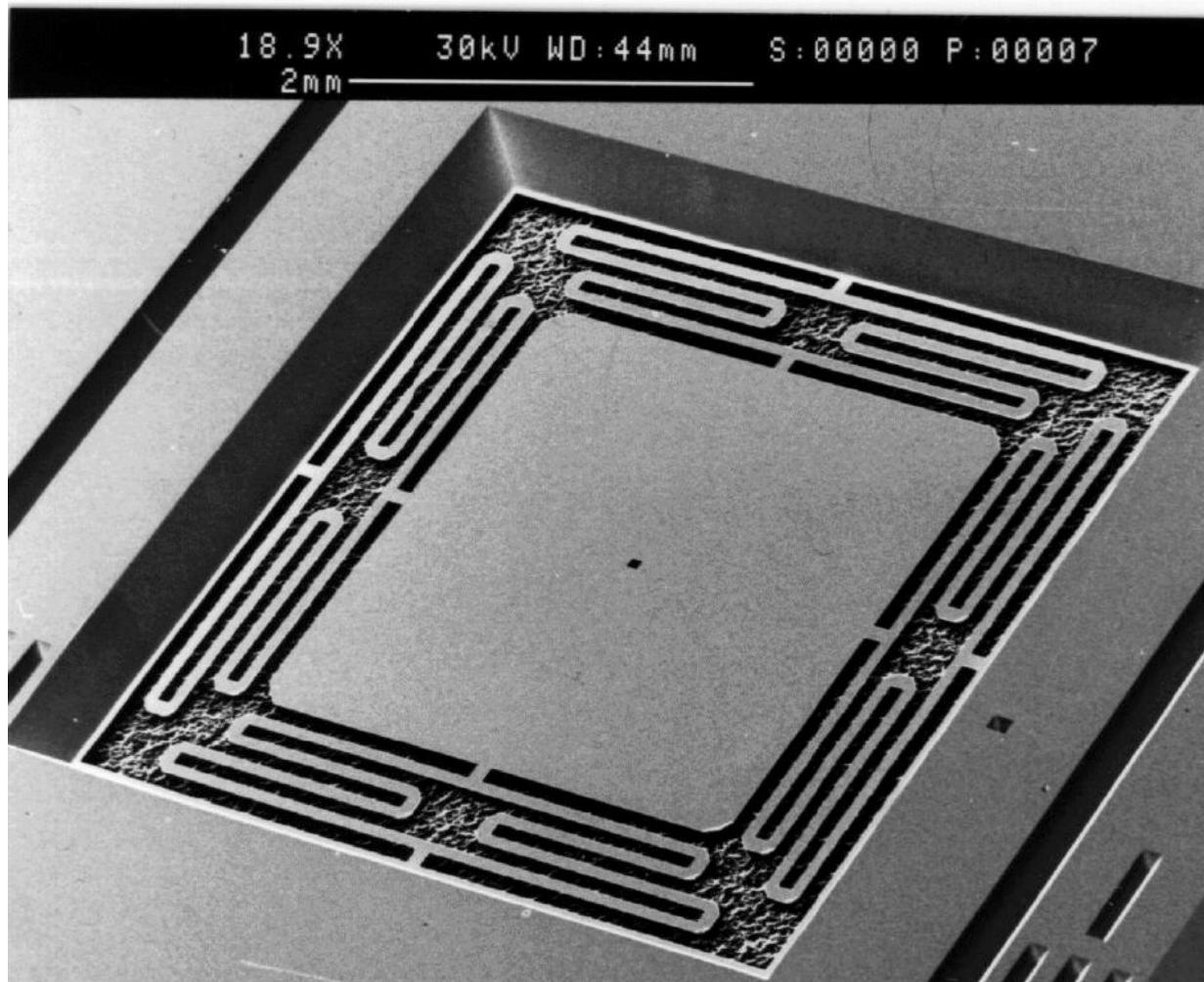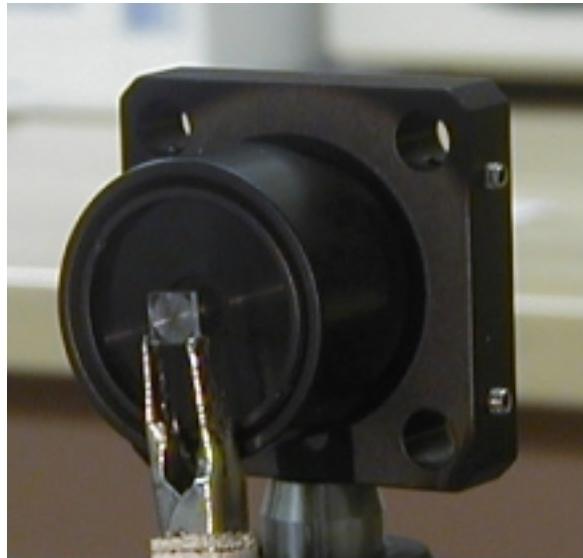
Spectrometer setup, D = 5mm, f = 5mm
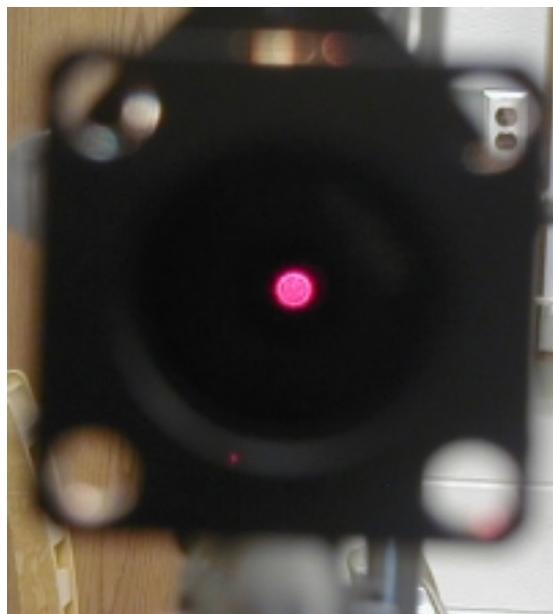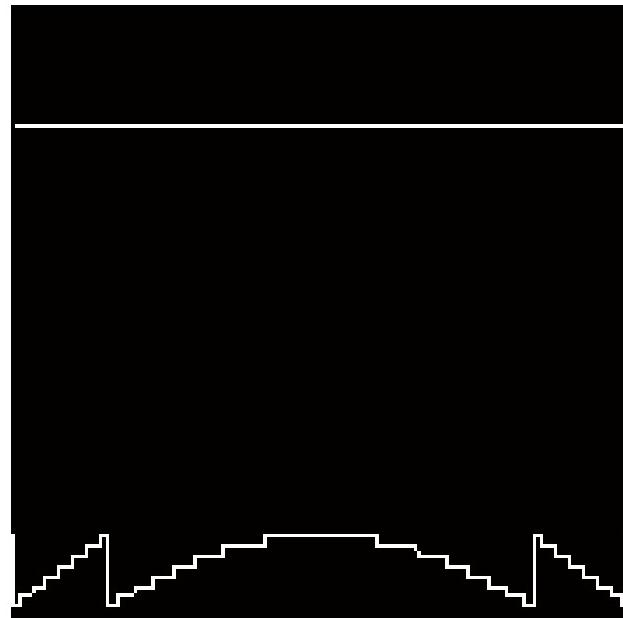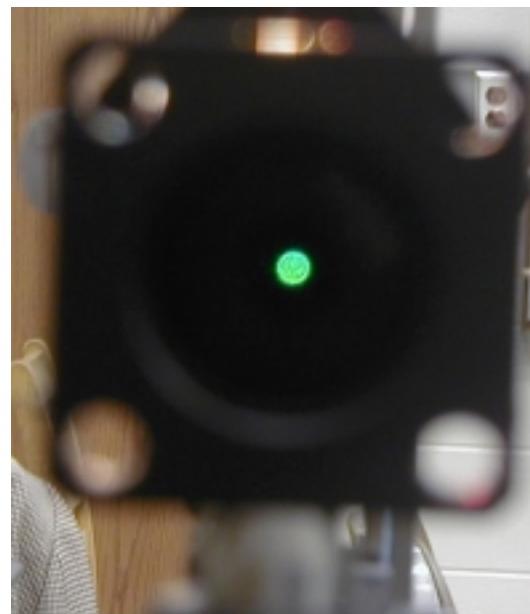

| 7.86mm | 9.8mm | 11.41mm |

# Application I: Lens Design
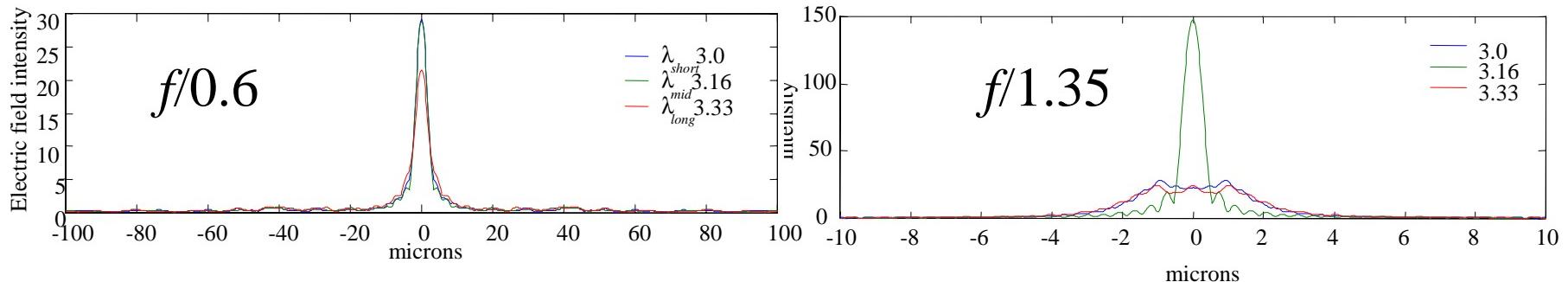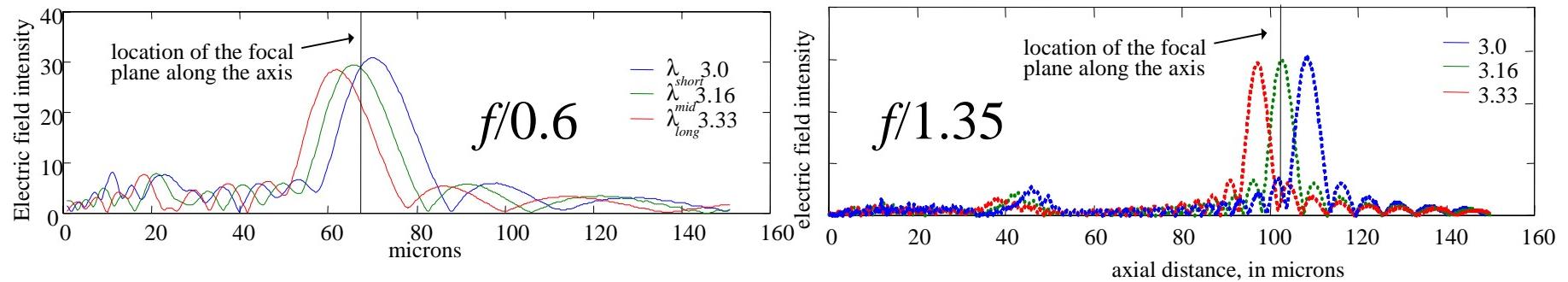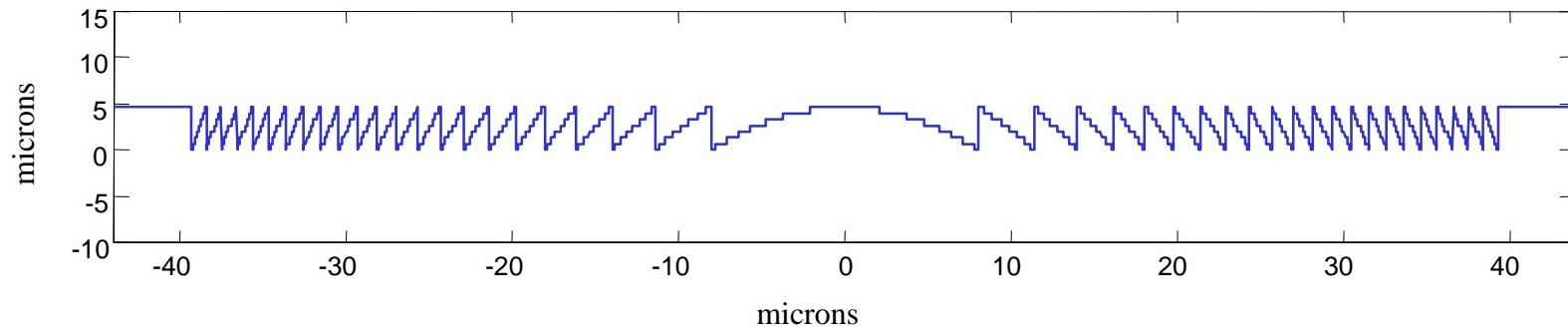
Electromagnetic-Based DOE Optimization
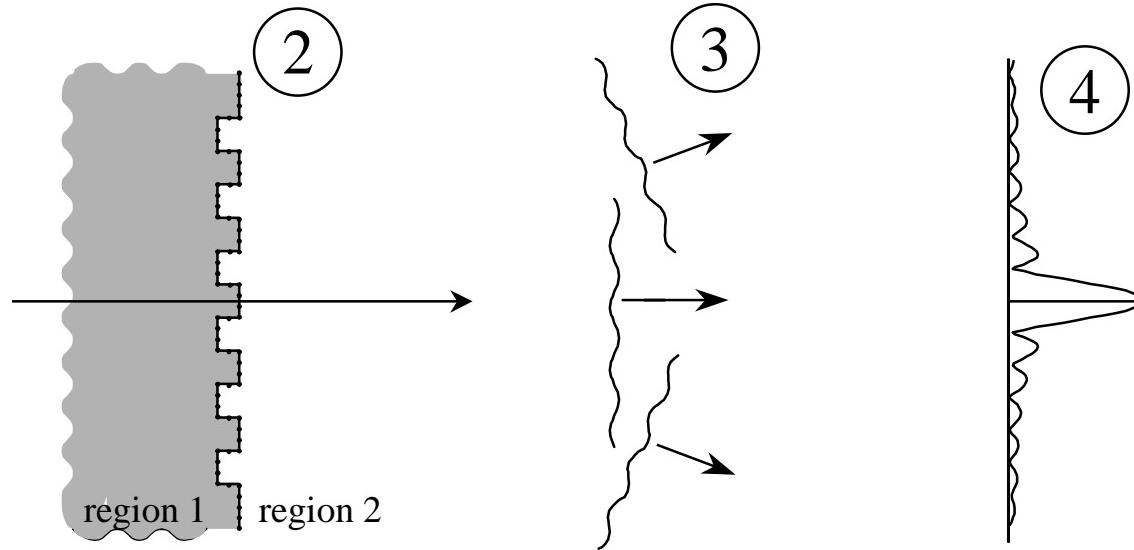
1. initial guess
2. use rigorous electromagnetic model to analyze DOE
3. evaluate performance
4. optimize performance metric

Repeat

Wavelet-Based Optimization Method

Wavelet Decomposition Process
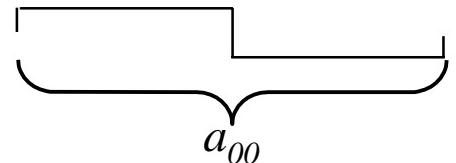
Zeroth order Haar Wavelet, $a_{00}\psi(x)$

a_{00}
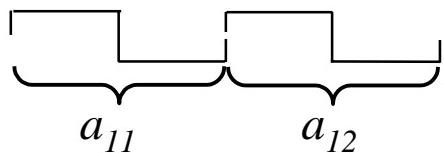
First order Haar Wavelets, $a_{1m}\psi(2\ x-m)$

a_{11} a_{12}
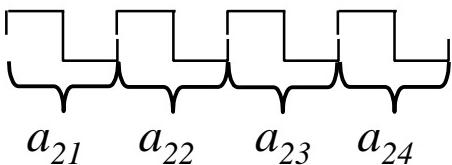
Second order Haar Wavelets, $a_{2m}\psi(2^2 x-m)$

a_{21} a_{22} a_{23} a_{24}
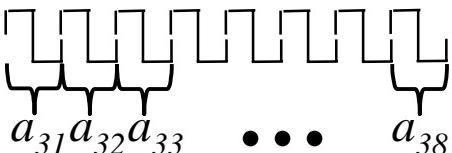
Third order Haar Wavelets, $a_{3m}\psi(2^3 x-m)$

$a_{31}a_{32}a_{33}$ $\cdots$ a_{38}

$$\sum_{n,m} a_{n,m}\psi(2^n x-m) \implies$$
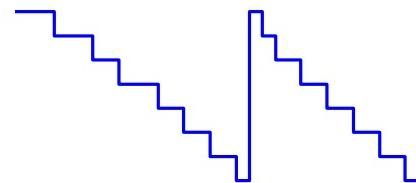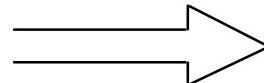
Diffractive Profile

Profile and Efficiency Improvements
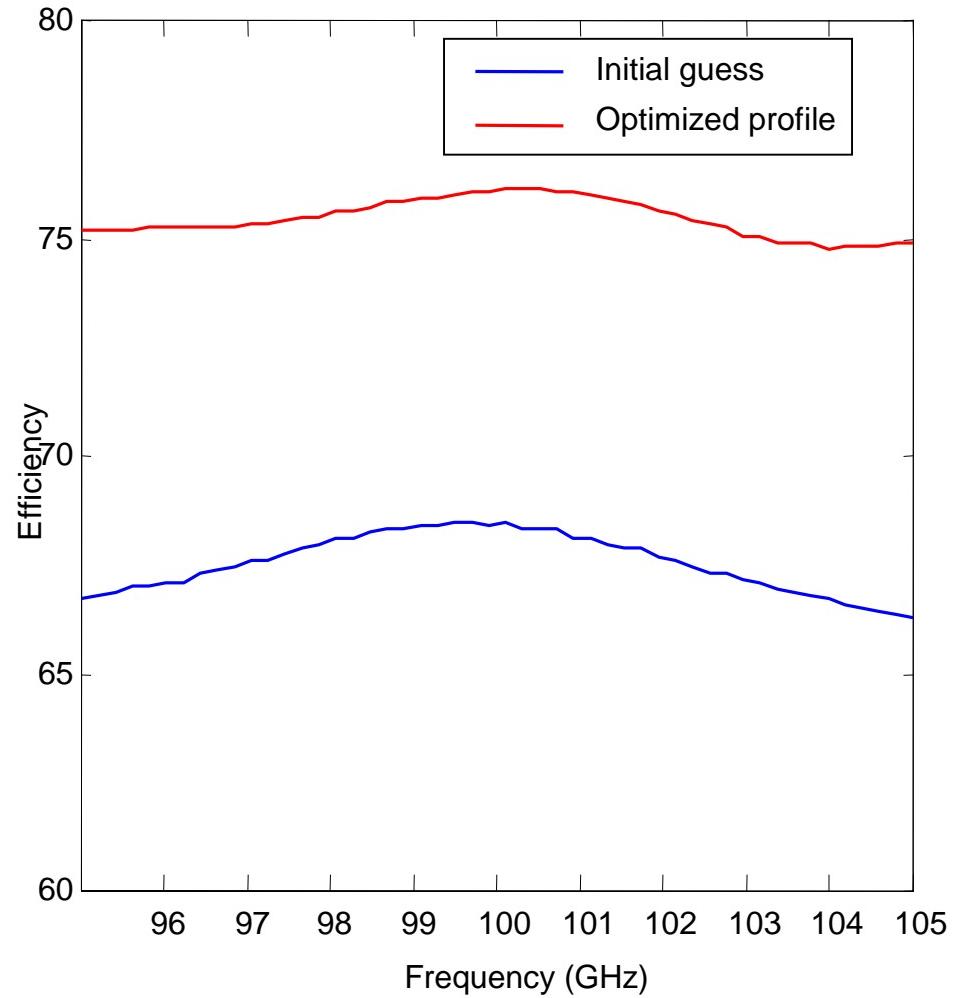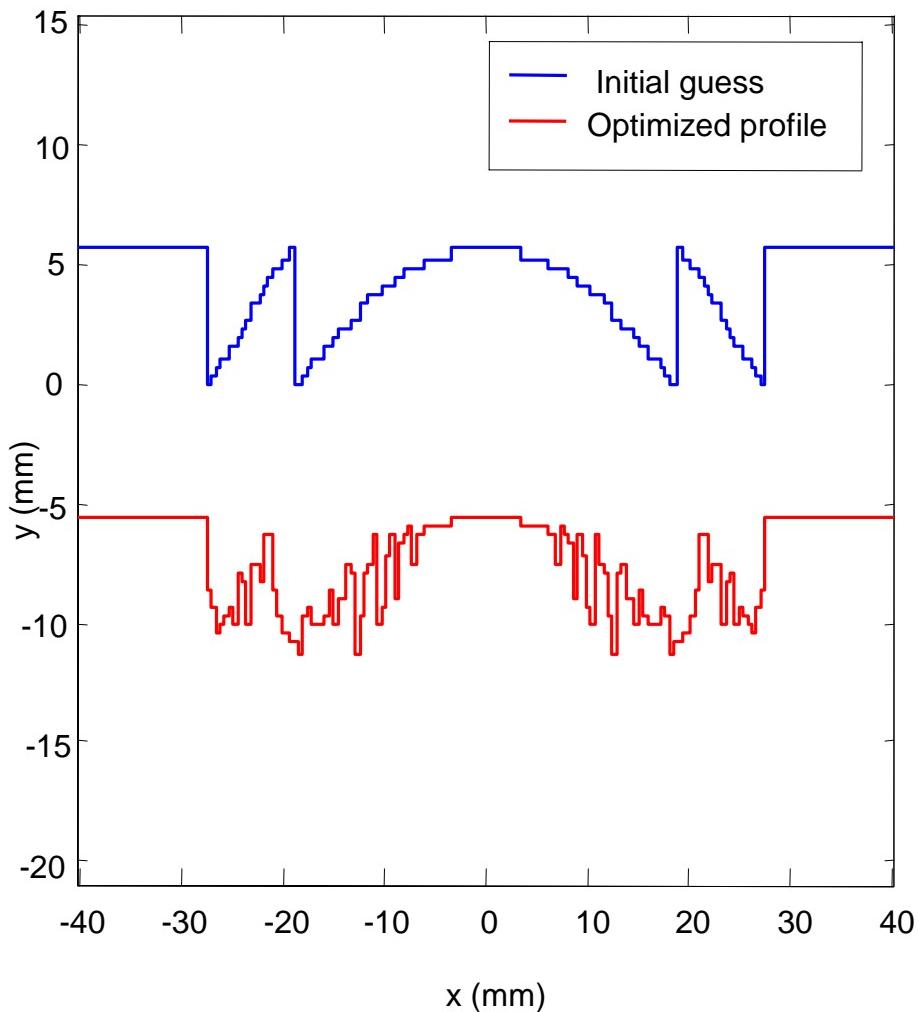
Fabrication of Grayscale Mesoscopic DOEs

Outer zones of an 8-level EM optimized DOE
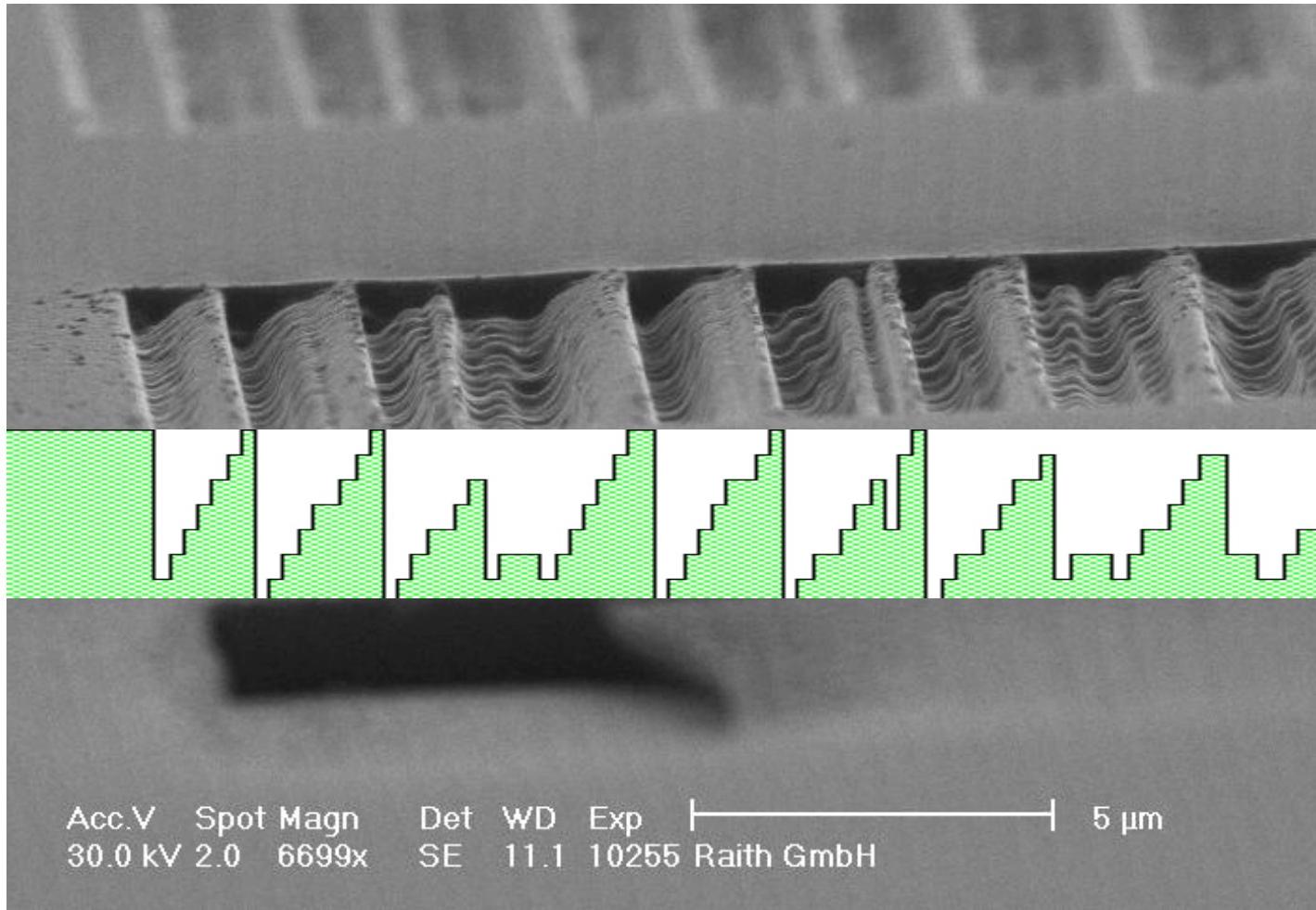
Application II: Photonic Band Gap Devices

- PBG's guide light based on the scattering properties created by tailoring the surface profile.
- They have a strong spectral dependence, which can be exploited in design.

$\varepsilon_r = 11.6$
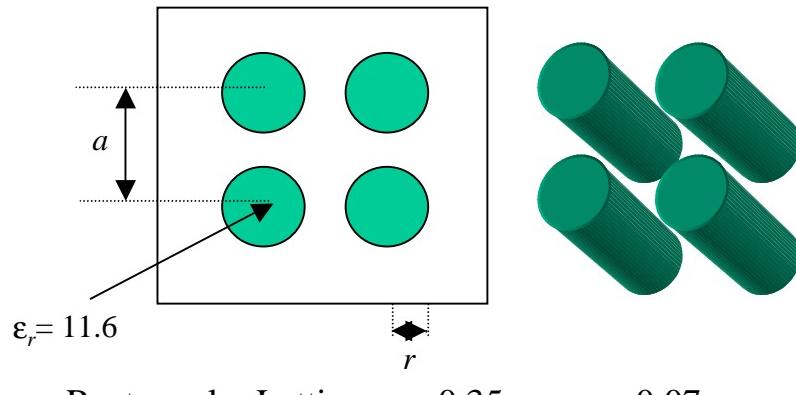
Rectangular Lattice: $a = 0.35$ μm, $r = 0.07$ μm
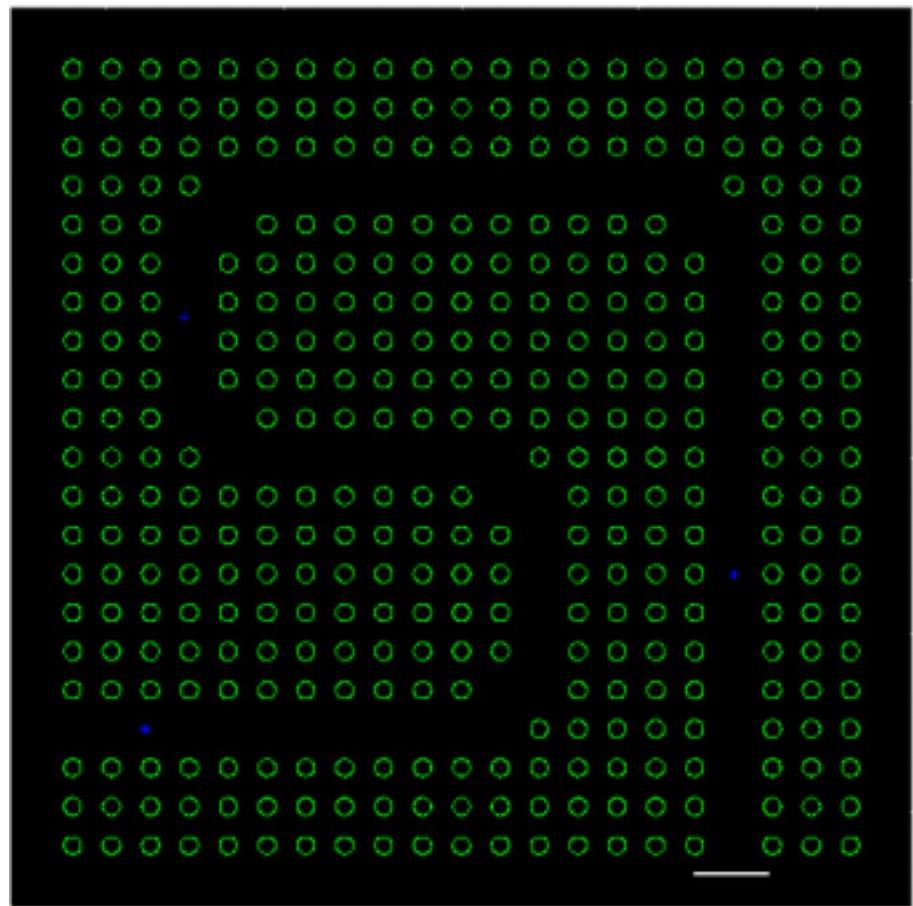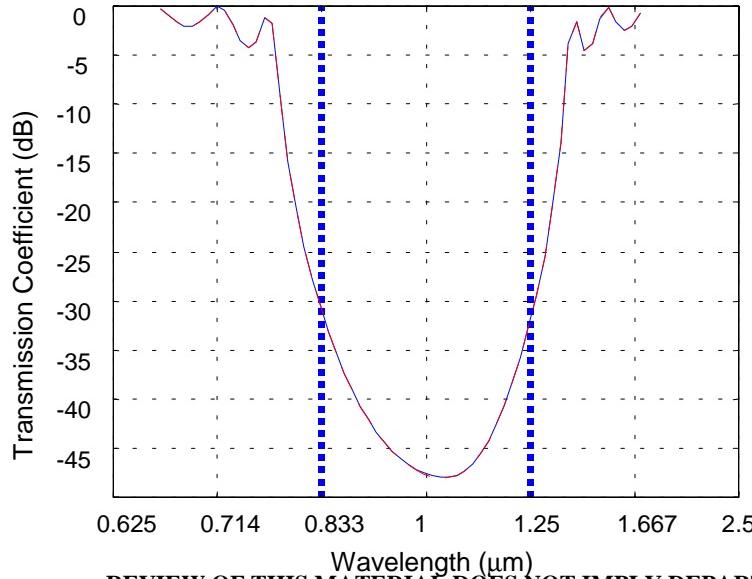
WDM Filtering using Two Cavities
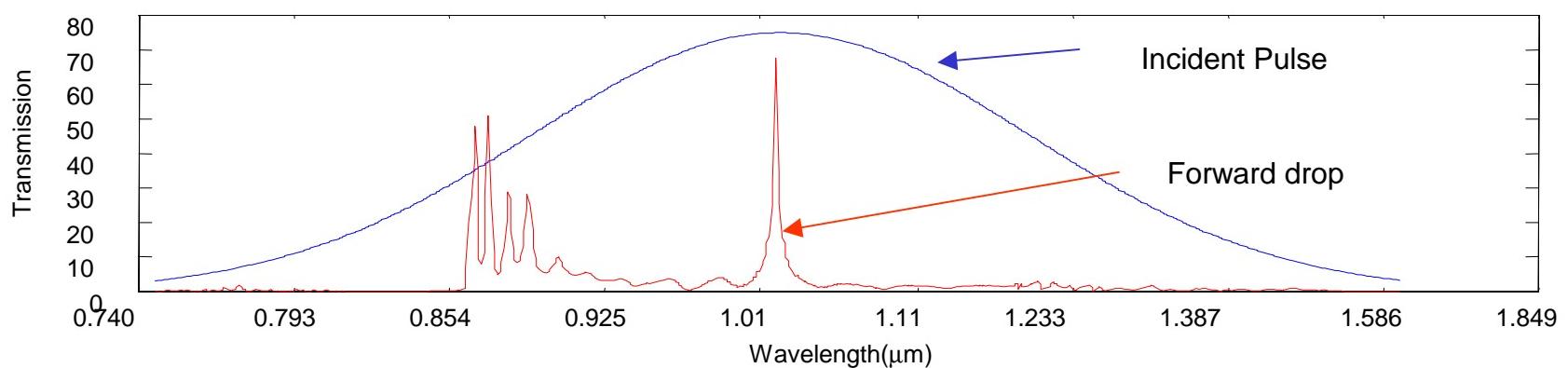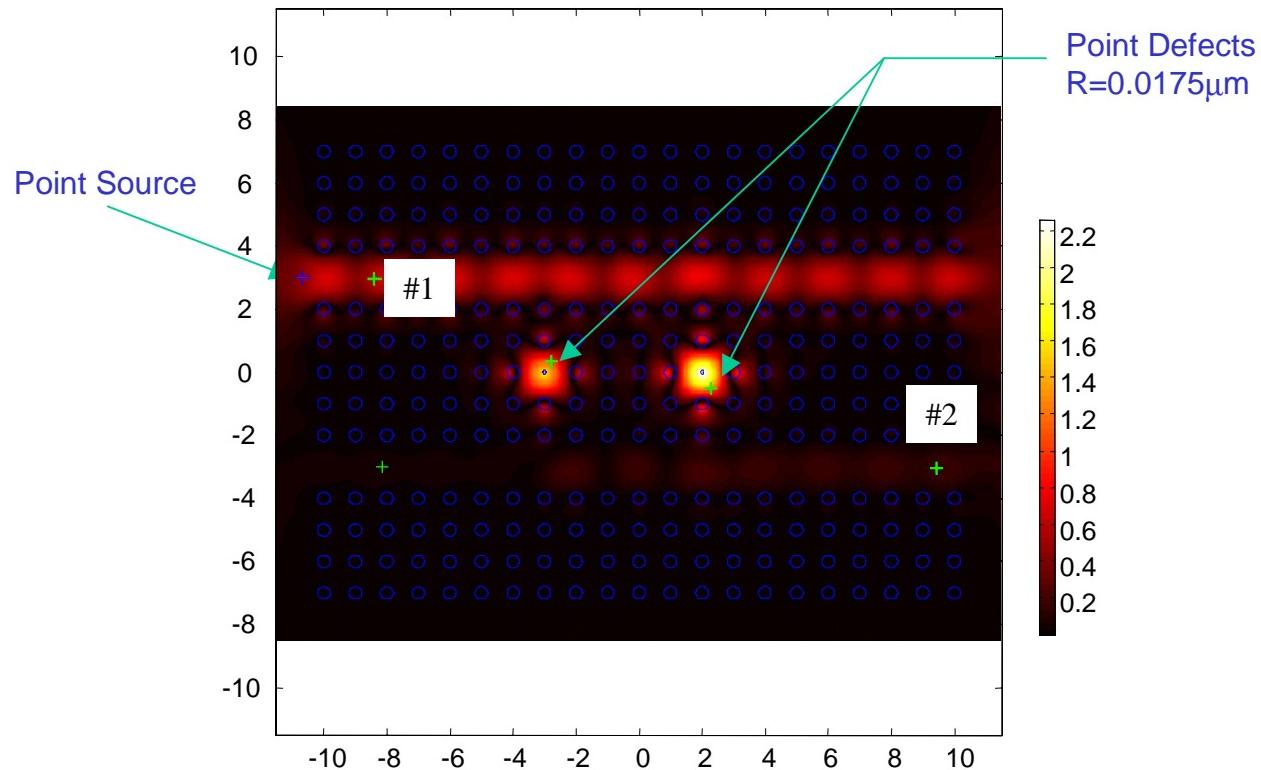
6 Channel WDM Filtering using Single Cavity Filters
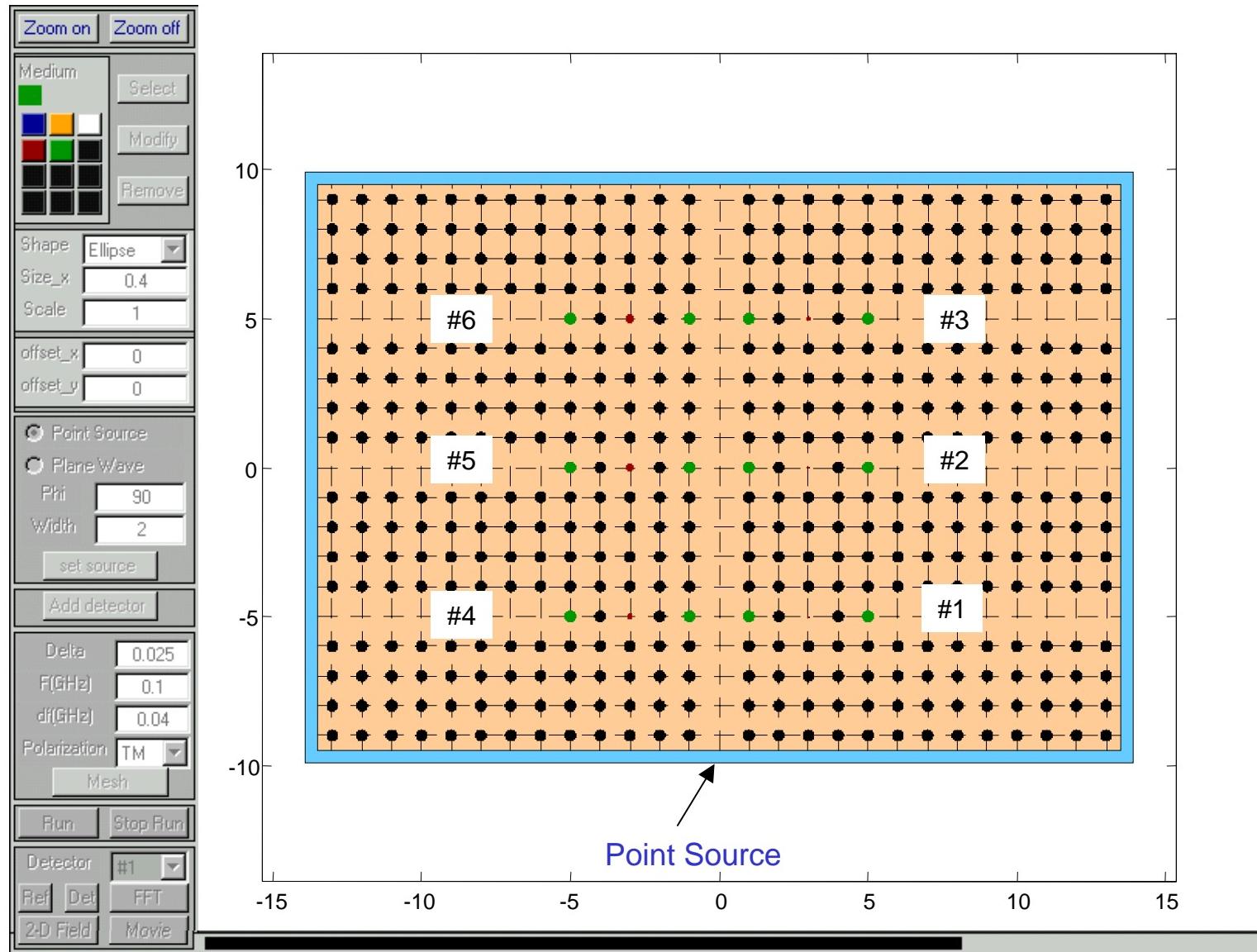
6 Channel WDM Filtering using Single Cavity Filters
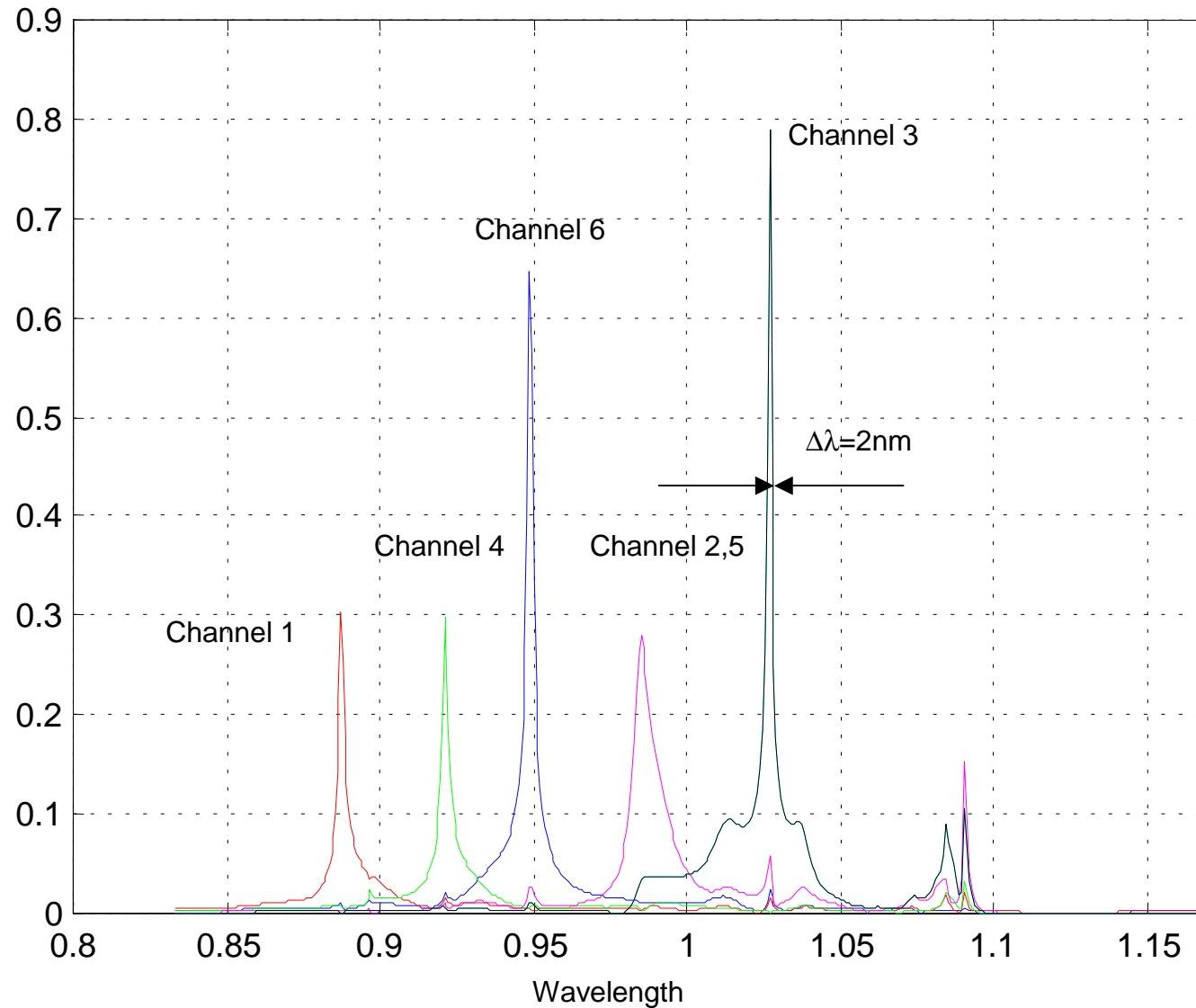
Parameterization Method for Semiconductor Amplifier

Input

material :
  effective mass
 dipole moment
Structure:
  well width
  barrier height
  energy bands

Susceptibility

$\chi(t)$ in time domain
$\chi(\omega)$ in frequency domain

Polarization

$P(\omega) = \varepsilon \, \chi(\omega) E(\omega)$
$P(t) = \varepsilon \, \chi(t) * E(t)$

Equivalent Susceptibility Using Prony method

$\chi(t) = \sum G_i e^{(\alpha_i + \omega_i) t}$

$\chi(\omega) = \sum G_i / [j(\omega - \omega_i) - \alpha_i]$

Superposition of finite modes N

Propagation with FDTD

Based on
Maxwell's Equations

Gain and phase shift

Perform FFT on Data obtained
from FDTD computation

Applications

• Laser Amplifiers
• Laser cavities
  VCSELS, QWs

FDTD Results: $N = 12e18/cm^{-1}$

Semiconductor Gain Modeling in FDTD

GaAs :

Injected carrier: N=9e24/m^{-3}
Dephasing time: T$_2$=0.1ps
Central frequency: f=3.52 10^{14}Hz

A = -2.0896e+029
B = -3.6279e+043
ω_0 =2.4125e+015
ω_t = 1.7361e+014

Equivalent conductivity

$\sigma = (j\,\omega\,A + B)/(\omega^2_o - 2j\omega_o\omega - \omega^2)$

Sinusoidal point source
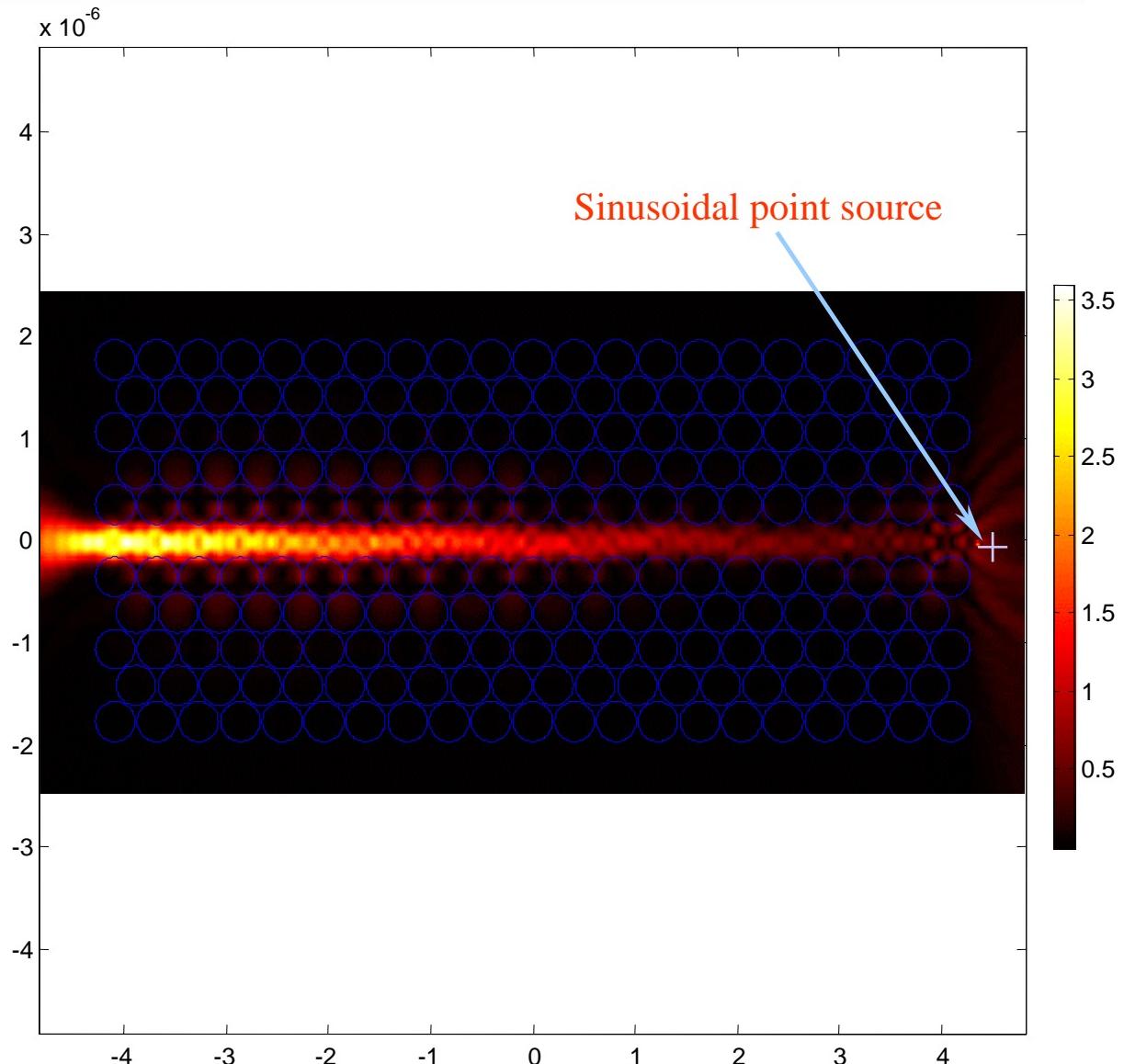
Summary

- Discussed the electromagnetic analysis and design of diffractive lenses and photonic band gap devices.

- Presented two applications for WDM
    - Embedded spectrometer
    - Photonic band gap filtering

- Introduced Wavelet based multiresolution optimization of diffractive lenses.

- Showed $f/\#$ dependence chromatic dispersion and its effect on spectral filtering.

- Channel drop filters based on an array of single cavity photonic band gap channels.